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INTERIM REPORT

MAINTENANCE AND OPERATION OF THE MULTISPECTRAL DATA-COLLECTION AND REPRODUCTION FACILITIES OF THE WILLOW RUN LABORATORIES

January 1970 Through June 1971

by

Philip G. Hasell, Jr., and Stephen R. Stewart

INFRARED AND OPTICS DIVISION
WILLOW RUN LABORATORIES
INSTITUTE OF SCIENCE AND TECHNOLOGY
THE UNIVERSITY OF MICHIGAN

Prepared for

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NASA Manned Spacecraft Center
Houston, Texas 77058
William Shaw/TC, Project Manager
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FOREWORD

The maintenance and operation of the multispectral data-collection and reproduction facilities at the Willow Run Laboratories of the Institute of Science and Technology, The University of Michigan, are described in this interim report. The work was performed under Contract NAS 9-9304 for the National Aeronautics and Space Administration, Manned Spacecraft Center, Houston, Texas. The period of research extends from January 1970 through June 1971.

Mr. Richard Legault, Head of the Infrared and Optics Division, is Project Director, and Mr. Philip G. Hasell, Jr., is Principal Investigator. NASA's Technical Monitor for the project is William Shaw/TC.

The Willow Run Laboratories' number for this report is 25990-37-P.

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ABSTRACT

This report summarizes the accomplishments in multispectral mapping during 1970 and (fiscal year) 1971; the mapping was done with the instrumented C-47 aircraft owned and operated by Willow Run Laboratories of The University of Michigan. Specific information for flight operations sponsored by NASA/MSC (Manned Spacecraft Center) in 1970 and fiscal year 1971 is presented, and a total listing of flights for 1968, 1969, 1970, and fiscal year 1971 is included in the appendices. A brief description of Willow Run Laboratories' multispectral data-collection and reproduction facilities is also included.

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January 1970 Through June 1971

SUMMARY

During 1970 and fiscal year (FY) 1971, the Willow Run Laboratories' (WRL) airborne multispectral data-collection system was maintained in a state of operational readiness and accomplished 26 of the 36 NASA-assigned missions. Of these 36 missions, 5 were cancelled because of unsuitable weather at the site, and 4 others were cancelled by NASA. One mission was rescheduled because of bad weather. Over 60,000 ground track miles of scanner imagery were recorded on magnetic tape in ultraviolet, visible, and infrared wavelengths. About one-quarter were reproduced on film for visible analysis. All tape-recorded scanner data are available on duplicate magnetic tapes in analog form suitable for machine processing. Scanner boresight aerial photography was obtained simultaneously with various film/filter combinations at all sites.

The instrumentation and procedures used to obtain these data are described briefly, and recommendations are made for continued use and improvement of the system.

1
INTRODUCTION

The primary purpose of this contract, which is now into its third year, is to maintain the Willow Run Laboratories' (WRL) airborne instrumentation and ground-based data-reproduction facilities in a state of operational readiness for multispectral data-collection missions. A total of 21 missions were authorized during 1969; 20 were successfully completed. This report summarizes the accomplishments of 1970 and the first half of 1971, during which a total of 36 missions were authorized and 26 successfully completed. Of these 36 missions, 28 were authorized in 1970 and 8 in the first six months of 1971. A total listing of NASA-sponsored missions planned and completed during this period is shown in Tables 1 and 2.

TABLE 1. SUMMARY OF NASA-SPONSORED MISSIONS IN 1970

NASA Mission No.	Site	Data User	Application	Mission Date Actual	Mission Date Planned	Flight-Line (miles) Actual	Flight-Line (miles) Planned
11M	Biscayne Bay, Florida	USGS/WRL	Hydrobiology	3/10	3/9-13	128	126
11M	Florida Keys, Florida	USGS/WRL	Hydrobiology	3/11	3/9-13	65	45
11M	Alafia/Peace, Florida	USGS	Hydrobiology	*	3/16-20	-	227
12M	Lafayette, Indiana	Purdue	Agriculture	5/6	4/13-17	279	257
13M	Ann Arbor, Michigan	WRL	Forestry	**	5/4-8	-	50
14M	North Dakota	USGS	Geological Survey	5/22-23	5/18-22	288	248
15M	Ann Arbor, Michigan	WRL	Forestry	6/8	6/8-12	38	80
15M	Washtenaw, Michigan	WRL	Agriculture	6/20	6/15-19	80	78
16M	Mill Creek, Oklahoma	USGS	Geology	6/23-26	6/22-26	450	258
17M	Lafayette, Indiana	Purdue	Agriculture	6/30, 7/1	6/29-7/3	268	354
18M	Ann Arbor, Michigan	WRL	Forestry	7/6-7	7/20-24	77	66
19M	Manitou, Colorado	USDA	Forestry	7/28-29	8/3-7	73	54
19M	North Dakota	USGS	Geological Survey	7/31	7/27-31	112	120
20M	Ann Arbor, Michigan	WRL	Forestry	8/5	8/24-28	62	70
20M	Lafayette, Indiana	Purdue	Agriculture	8/11-13	8/10-14	233	260
20M	Washtenaw, Michigan	WRL	Agriculture	8/21	8/17-21	78	78
21M	Catheart Mt., Maine	USGS	Geological Survey	8/27	8/25-28	22	24
22M	Alafia/Peace, Florida	USGS	Hydrobiology	9/18-21	9/14-18	323	168
22M	Tenn. Valley, Tennessee	Purdue	Forestry	**	9/21-23	-	120
23M	Lafayette, Indiana	Purdue	Agriculture	**	9/21-25	-	257
24M	Ann Arbor, Michigan	WRL	Forestry	9/29, 10/2	9/28-10/2	71	66
25M	Lafayette, Indiana	Purdue	Agriculture	**	10/19-23	-	261
26M	Ann Arbor, Michigan	WRL	Forestry	10/16	10/12-16	58	66
27M	Lafayette, Indiana	Purdue	Agriculture	**	12/7-11	-	257
28M	Indiana Grain Belt	Purdue	Agriculture	8/24	8/24	124	124
28M	Indiana Grain Belt	Purdue	Agriculture	9/5	9/1-4	196	196
28M	Indiana Grain Belt	Purdue	Agriculture	9/11	9/7-11	124	124
29M	Chesapeake Bay, Maryland	NASA/Wallops	Oceanography	11/4-6	11/2-6	159	177
31M	Pisgah Crater, California	WRL	Geology	10/29-30	10/26-30	60	60
						3368	4271

*Postponed because of unsuitable weather; later reflown

**Cancelled because of unsuitable weather

TABLE 2. SUMMARY OF NASA-SPONSORED MISSIONS DURING JANUARY THROUGH JUNE OF 1971

NASA Mission No.	Site	Data User	Application	Mission Date Actual	Mission Date Planned	Flight-Line (miles) Actual	Flight-Line (miles) Planned
32M	Weslaco, Texas	USDA	Agriculture	2/27, 3/3-4	3/1-3	135	74
33M	Lafayette, Indiana	Purdue	Agriculture	*	3/15-19	-	-
34M	Tenn. Valley, Tennessee	Purdue	Forestry	3/11	2/25-26	90	110
35M	Houston, Texas	NASA/MSC	Water Pollution	3/8-9	3/4-5	243	213
36M	Lafayette, Indiana	Purdue	Agriculture	*	4/5-9	-	-
37M	No. Great Plains		Soil Limitations	*	5/17-21	-	-
38M	Corn Belt, Indiana	Purdue/WRL	Agriculture	5/17, 21-22	5/17-28	307	305
39M	Ann Arbor, Michigan	WRL	Forestry	*	5/31-6/4	-	-
						775	702

*Cancelled by either principal investigator or NASA

2
ACCOMPLISHMENTS

The accomplishments during the contract period from 1 February 1970 through 30 June 1971 are discussed in this section.

2.1. FACILITY MAINTENANCE

The facility was maintained in a state of operational readiness throughout the contract period. No disruptions of the mission schedule occurred because of major equipment malfunctions. On a secondary priority basis, periodic maintenance was performed on the aircraft and instrumentation equipment throughout the year. The periodic aircraft maintenance is normally completed on a programmed 50 flight-hour schedule. All maintenance was done at WRL, since no mission exceeded the 50 flight-hour limit. A total of 283 aircraft flight hours were accumulated in support of NASA-sponsored missions during the contract period.

Instrumentation in the aircraft and in the laboratory was repaired, maintained, and calibrated between scheduled missions as time permitted. The first priority maintenance was assigned to multispectral scanning equipment, which was maintained in good working order throughout the year. The aerial cameras, which provide boresight photography for the scanners, were maintained on a secondary priority basis because their data are of secondary importance in multispectral analysis. Since an attempt was made to operate all available cameras as requested, maintenance was limited to obvious malfunctions; spares were not available to replace cameras of questionable performance. In addition, the cameras were often operated, as requested, beyond their performance limitations with regard to adequate exposure with a specific film/filter combination. As a result, the aerial photography was often of poor quality, but it was adequate to document the boresight view of the multispectral scanners.

In addition to periodic performance checks, the multispectral scanner equipment underwent complete calibration checks in June and December of 1970 and in February and May of 1971. These calibration tests are used to establish the system's response over the entire scan field of view (FOV) in terms of absolute radiant energy at the scanner aperture for each of the scanner data channels. A total of six calibration checks have been performed on the system since its assembly in early 1966.

During the contract period, we assisted NASA/MSC in planning and scheduling data-collection missions with the C-47 aircraft. We discussed mission requirements and made plans for the 36 missions which were eventually authorized under the contract. WRL personnel participated in all of the mission-planning meetings held at NASA/MSC during 1970 and FY 1971.

2.2. DATA-COLLECTION MISSIONS

A total of 36 missions were authorized during the contract period, 28 in 1970 and the remaining 8 in the first six months of 1971. Of the 28 flown in 1970, 22 were successful. After authorized standby time at the site, the remaining six were cancelled because of unsuitable weather conditions. One of these cancelled missions (Alafia/Peace) was later flown under a new mission number and was included as one of the 22 successful missions mentioned above. The other five cancelled missions included: one at Ann Arbor, Michigan; one at Tennessee Valley, Tennessee; and three at Lafayette, Indiana. Of the eight missions authorized in the first half of 1971, the four undertaken were completed successfully. The remaining four were cancelled either by the Principal Investigator or by NASA in order to allow sufficient preparation time and funds for the Corn Blight Watch in 1971.

As shown in Fig. 1, the mission sites were located throughout the continental United States. Some sites, such as Lafayette, Indiana, and Washtenaw County, Michigan, were mapped several times on separate missions. During this reporting period, over 4000 ground track miles were flown, producing approximately 60,000 sq miles of scanner imagery and another 10,000 sq miles of aerial photography. From February 1970 to June 1971, 75 separate flight operations were flown for NASA. For FY 1971 (July 1970-June 1971), approximately 50,000 sq miles of scanner imagery and aerial photography were obtained at an approximate cost of $10.00/sq mile of imagery, with an average of 18 data channels used per mission.

The data recorded and reproduced from these NASA flights are tabulated in Tables 3 and 4. All flights (both NASA and non-NASA) flown during 1970 and FY 1971 are listed by date and time in Appendices III and IV. The listings show the number of data channels in the various spectral bands requested during the 112 flights made in that period. For comparison, Appendix I shows the 19 flights (including 2 NASA flights) made in 1968 and Appendix II, the 80 flights (including 55 NASA flights) made in 1969. Appendix V presents a tentative flight schedule for FY 1972. FY 1972.

We planned and conducted a particular mission in accordance with a flight request prepared by the Principal Investigator and approved and supplied to us by NASA/MSC. We satisfied the mission requirements, within the limitations of allotted time at the site, weather conditions, allotted expendable materials, and allotted aircraft flight hours. The success of past missions can be determined by a comparison of the planned and actual flight-line miles listed in Table 1. Most of the missions were considered successful. Unsuitable weather during the allotted time period restricted the amount of data collected on some, but none were resticted by allotted expendable material or aircraft flight hours.

The procedure for handling the large quantity of data collected on these missions is as follows:

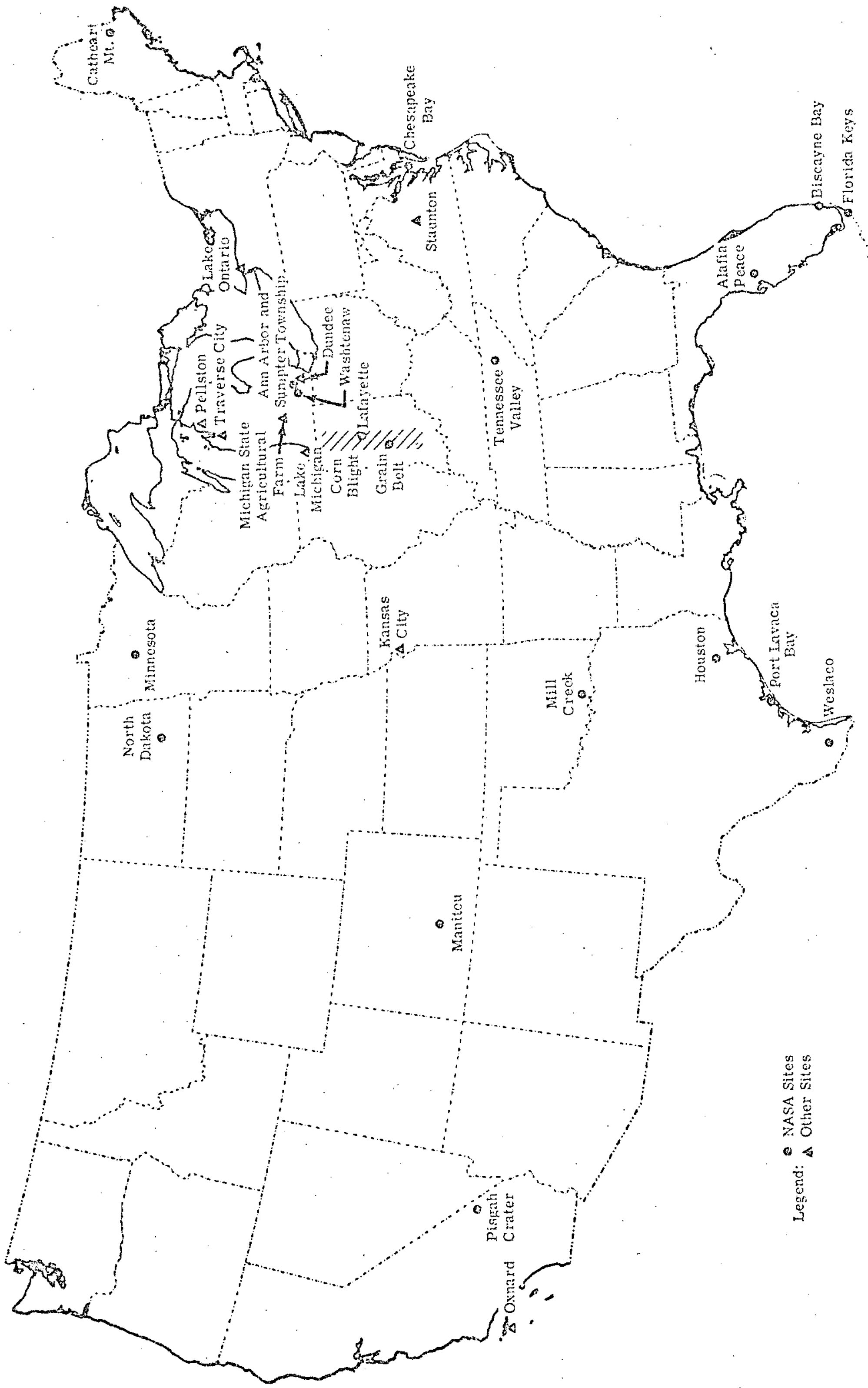

FIGURE 1. SITES OF MULTISPECTRAL DATA COLLECTION FLIGHTS IN 1970 AND FISCAL YEAR 1971

TABLE 3. SUMMARY OF DATA OBTAINED AND DISTRIBUTED IN 1970 FOR NASA-SPONSORED MISSIONS

Missions Flown*			Tape-Recorded Scanner Data**			Scanner Data*** Reproduced		Rolls of**** Aerial Camera Data		
NASA Mission No.	Date	Site	Original 1-in. Tapes	Original 1/2-in. Tapes	Duplicate 1-in. Tapes	No. of Film Rolls	Data (Miles)	70-mm Color	70-mm B&W	9.5 in. B&W
11M	3/10-11	Biscayne/Keys, Florida	10	10	0	2	736	8	0	2
12M	5/6	Lafayette, Indiana	24	0	24	2	1116	6	0	2
14M	5/22-23	North Dakota	24	0	0	1	992	16	0	0
15M	6/8	Ann Arbor, Michigan	4	0	0	1	152	2	2	0
15M	6/20	Washtenaw, Michigan	8	0	0	1	320	3	3	0
16M	6/23-26	Mill Creek, Oklahoma	30	0	0	2	1160	0	0	0
17M	6/30, 7/1	Lafayette, Indiana	25	0	25	2	1060	8	0	3
18M	7/6-7	Ann Arbor, Michigan	8	0	0	1	308	4	4	0
19M	7/28-29	Manitou, Colorado	8	0	0	1	292	4	0	2
19M	7/31	North Dakota	8	0	0	1	448	2	0	1
20M	8/5	Ann Arbor, Michigan	5	0	0	1	218	4	1	1
20M	8/11-13	Lafayette, Indiana	22	0	22	2	932	12	0	3
20M	8/21	Washtenaw, Michigan	8	0	0	1	382	4	2	1
21M	8/27	Catheart Mt., Maine	3	0	0	1	88	2	2	0
22M	9/18-21	Alafia/Peace, Florida	21	0	0	2	1048	5	4	0
24M	9/29, 10/2	Ann Arbor, Michigan	8	0	0	2	284	5	0	2
26M	10/16	Ann Arbor, Michigan	9	0	0	1	232	2	2	0
28M	8/24	Indiana Grain Belt	12	0	12	1	496	4	0	2
28M	9/5	Indiana Grain Belt	18	0	18	1	784	0	0	2
28M	9/11	Indiana Grain Belt	12	0	12	1	496	0	0	1
29M	11/4-6	Chesapeake Bay, Maryland	18	0	16	1	636	4	6	0
31M	10/29-30	Pisgah Crater, California	7	0	0	1	280	4	0	1
			292	10	129	29	12,460	99	26	23

*Original flight data records retained at Willow Run Laboratories; copies of records sent to NASA/MSC and principal investigators.

**All original tapes retained at WRL; duplicate analog tapes sent to the principal investigator.

***All original scanner imagery reproduced on film sent to NASA/MSC.

****All original aerial camera film sent to NASA/MSC.

TABLE 4. SUMMARY OF DATA OBTAINED AND DISTRIBUTED DURING JANUARY THROUGH JUNE 1971 FOR NASA-SPONSORED MISSIONS

Missions Flown*			Tape-Recorded Scanner Data**			Scanner Data*** Reproduced		Rolls of*** Aerial Camera Data		
NASA Mission No.	Date	Site	Original 1-in. Tapes	Original 1/2-in. Tapes	Duplicate 1-in. Tapes	No. of Film Rolls	Data (Miles)	70-mm Color	70-mm B&W	9.5-in. B&W
32M	2/27, 3/3-4	Weslaco, Texas	10	0	0	1	540	1	7	0
34M	3/11	Tenn. Valley, Tennessee	10	0	10	1	360	2	2	0
35M	3/8-9	Houston, Texas	20	0	20	1	972	3	4	2*****
38M	5/17, 21-22	Corn Belt, Indiana	34	0	0	2	1228	2	4	3
			74	0	30	5	3100	8	17	5

*Original flight data records retained at Willow Run Laboratories; copies of records sent to NASA/MSC and principal investigators.

**All original tapes retained at Willow Run Laboratories; duplicate analog tapes sent to the principal investigator.

***All original scanner imagery reproduced on film sent to NASA/MSC.

****All original aerial camera film sent to NASA/MSC.

*****Color.

(1) The raw tape and film data are scheduled for processing and reproduction according to the order in which they arrive at WRL (usually with the aircraft) after a mission.

(2) All aerial camera film is stamped with identifying perforations by the camera operator and sent to the WRL photo laboratory, where the black and white film is processed and a paper file print made. The color film is sent by the photo laboratory to Data Corporation for processing. Black and white film is usually processed within one week and color film within two weeks.

(3) Within two weeks after the raw data are received at WRL, the original magnetic tapes are duplicated on request in analog form and sent either to NASA/MSC or to the Principal Investigator with a rough copy of the flight data records. The 1-in. tapes are duplicated one for one on 1-in. tapes; the 1/2-in. tapes are duplicated two for one on 1-in. tapes.

(4) Four selected channels of tape-recorded scanner data are reproduced on 70-mm film during the three weeks following the duplication of the data tapes. These scanner film imagery reproductions are made in the printing facility at WRL, and the photo laboratory processes film and makes a paper file print of the imagery.

(5) The flight data records prepared by the flight crew are completed and typed in final form during the three weeks following a mission. These flight records, which include maps, a narrative report, and instrument settings, constitute the mission documentation.

(6) The original aerial camera film transparencies, the original scanner imagery on film transparencies, and the flight data records are labeled by a data clerk and reviewed by the flight crew and test conductor before being packaged and shipped to NASA/MSC within a month after the mission. A paper print of all black and white imagery shipped is retained on file at WRL. In special cases, a second print of selected black and white imagery is also shipped directly to the Principal Investigator for the particular mission.

(7) The original analog magnetic tapes and original flight-data records for each mission are retained on file at Willow Run.

This procedure was followed except that the final typing of the flight-data records lagged behind schedule. However, the use of the data was not delayed because the flight information was distributed in rough form with the data.

2.3. MISSION DOCUMENTATION

In early 1971, the contract was amended to require that we document mission plans and accomplishments with draft reports prepared according to forms and formats, supplied by NASA.

NASA then converts these draft reports to NASA publications distributed by their publications group. The reports include a mission plan, prepared in response to the flight request from NASA/MSC and a Mission Report, which describes how well the approved mission plan was accomplished.

The mission plan and estimated cost are prepared by us and sent to NASA/MSC within two weeks after we receive the NASA-approved flight request and, hopefully, at least one month before the scheduled mission date. We are authorized to accomplish the mission requested by NASA/MSC after they have reviewed and approved the mission plan and estimated cost. Unfortunately, NASA-approved flight requests are often not received until the date of the scheduled mission, so we cannot always follow this procedure. However, since the contract requirement was established, we have always prepared a mission plan with cost estimates and submitted them to NASA/MSC promptly after receipt of the flight request.

A draft of the Mission Report is prepared and submitted to NASA/MSC within one month after the mission. The report essentially is a translation of our flight data records into NASA's format; it also includes additional information about the mission objectives and a brief description of the site. In this report, we also discuss why we made any deviations from the approved mission plan. Mission reports were prepared for all missions accomplished after the contract amendment and for many of the missions prior to the amendment.

3
BRIEF DESCRIPTION OF FACILITIES

The multispectral data-collection and reproduction facilities developed by WRL under government sponsorship are described briefly. The airborne system was first used operationally in early 1966 and has been used without significant change since that time.

3.1. AIRBORNE MULTISPECTRAL DATA-COLLECTION SYSTEM

Willow Run Laboratories have been active for many years in a program to develop signal-processing techniques for discrimination of selected targets by remote observation of their optical radiation characteristics. In the course of this program, it has been necessary to develop an airborne imaging sensor which can register the spectral properties of a terrain scene in absolute measure and in the form of an electrical signal.

Because of budget limitations, the resulting airborne data-collection system is configured around readily available airborne scanners originally developed for military reconnaissance. We obtained the 19 miltispectral data channels by using 4 detector assemblies, one installed in each end of two, dual-ended scanners. A choice of detector configurations is available, but the basic grouping for data collection has been:

(1) Scanner 1

End A: GeHg detector filtered for 8.0 to 13.5 μm

End B: InSb detector with 3 elements filtered for 1.0 to 1.4 μm, 2.0 to 2.6 μm and 4.5 to 5.5 μm

(2) Scanner 2

End A: Spectrometer with 12 photomultiplier detectors over a range of 0.4 to 1.0 μm

End B: InAs detector with 3 elements filtered for 1.0 to 1.4 μm, 1.5 to 1.8 μm and 2.0 to 2.6 μm

An assortment of detector/filter combinations is available for substitution in End B of each scanner. These include a photomultiplier filtered for 0.32 to 0.38 μm, single element InAs or InSb detectors with filters for any of the wavelength bands shown for the 3-element detectors, a single element HgCdTe detector with a selected wavelength band between 1.0 and 12.5 μm and a dual element HgCdTe detector with two wavelength bands between 8.2 and 12.1 μm.

Analog processing of the multispectral signals is limited to the output of any selected detector assembly, because the data must have a common aperture to be time synchronous. The multi-element detectors scan a ground target sequentially. The electrical signal from the lead elements is delayed to make their outputs approximately time synchronous.

The scanners* were modified to provide a single scanning-mirror surface for each detector assembly at a fixed scan rate of approximately 60 scans per second. The single scanning surface was selected (by covering one of the two scan mirror surfaces) in order to restrict the detector to a single radiation input at any one time. The scan rate selected was the maximum available for the particular scanner and was fixed to simplify scanner controls. Most of our data were collected at low altitudes. This required the maximum scan rates, and the scan overlap at higher altitudes was acceptable. With this scan rate and a normal aircraft ground speed of 120 knots, a continuous registration of terrain without scan overlap is obtained at an altitude of about 1000 ft. The scanning geometry is illustrated in Fig. 2.

For calibration of the radiation input to each detector channel, scanner 1 contains two thermal reference plates and a lamp radiation source, and scanner 2 contains two lamp sources and a solar reference source; these are registered in the detector outputs during each line scan. The thermal plates provide two blackbodies as temperature references for the thermal-IR channels (4.5-5.5 μm and 8-13.5 μm), and the lamps provide radiation reference levels corresponding to the reflected energy (from solar illumination) of typical targets in the data channels from 0.32 to 2.6 μm. The dark interior of the scanner is registered as the zero-radiation input for the scanner channels in the 0.32- to 2.6-μm region.

The electrical outputs of the radiation detectors are amplified for recording on tape recorders with an electrical bandwidth of from near dc to at least 20 kHz. With appropriate selection of amplifier gains, dc restoration, and special electronic filtering in the tape playback, a bandwidth of dc to 50 kHz can be realized. The information bandwidth of the scanner itself is approximately 70 kc. The separate detector outputs are displayed on oscilloscopes to the airborne operators, who select the appropriate amplifier gains to match each signal level to the dynamic range of the tape recorder. A separate tape machine records the output of each scanner.

Originally, a 7-channel recorder was used to accept one synchronization and up to 6 video signals from scanner 1, while a 14-track recorder was used to accept one synchronization and 13 video signals from scanner 2. However, in April, 1970, the 7-track tape machine was replaced by a second 14-track machine to provide the redundancy of two 14-track machines in the aircraft recording 21 data channels. If a tape machine malfunction occurs during field operations, at least 14 tracks of data could be recorded on the other machine.

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*This report assumes that the reader is familar with line scanners. For information on them, see M. R. Holter and W. L. Wolfe, "Optical-Mechanical Scanning Techniques," Proc. IRE. Vol. 47, No. 9, 1959, pp. 1546-1550.

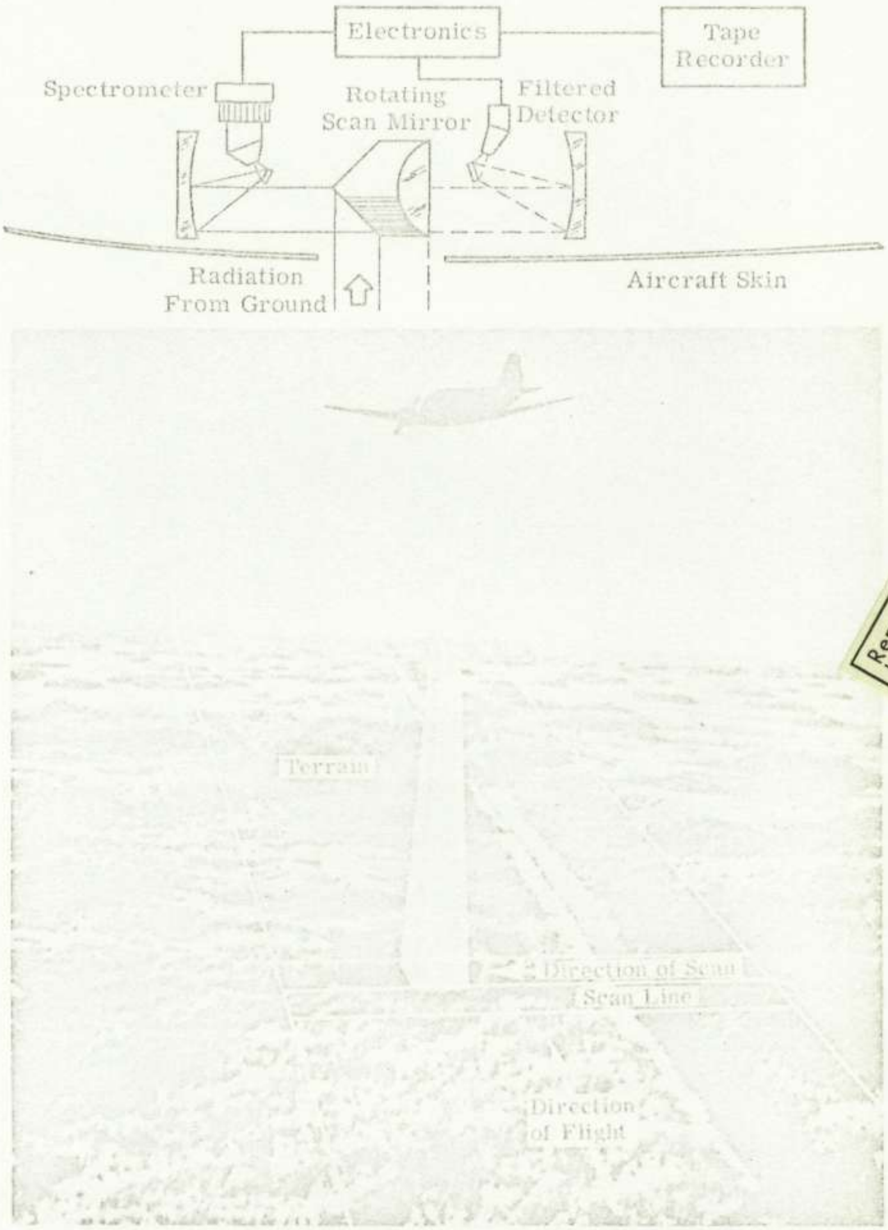

FIGURE 2. MULTISPECTRAL SCANNER OPERATION

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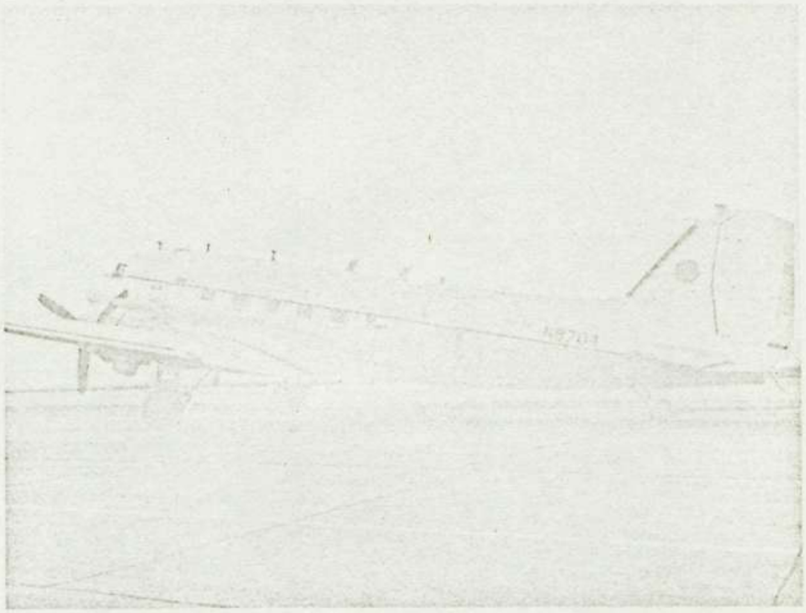
The aircraft in which the airborne sensor equipment is installed is shown in Fig. 3. The layout of equipment in the aircraft is shown in Fig. 4. Two instrumentation wells in the bottom, rear section of the aircraft house the ground-scanning equipment. Aerial cameras are mounted in the left well to make a photographic register of what the scanner maps; these photographs aid in data interpretation. The two scanners are located in the right well. Full operation of the airborne system requires a crew of seven: a pilot, a copilot, and a flight engineer for the aircraft; a test conductor and three equipment operators for the instrumentation. During flight, one equipment operator controls the aerial cameras and the direct printing of two data channels from scanner 2. The same video printing equipment can be operated on the ground to reproduce on film any selected channel from the tape-recorded data. The other two equipment operators monitor and control the signals and record general data associated with each pair of scanners and tape recorders.

System performance is adequate for registration of terrain in all scanner data channels during daylight hours under all weather conditions suitable for visual flight rules (VFR) aircraft operation; however, there can be no clouds between the aircraft and the terrain. Only the thermal channels (4.5 to 5.5 μm and 8 to 13.5 μm) are operable at night or twilight. Data can be collected at flight altitudes from 500 ft above terrain to 15,000 ft above sea level. However, at 500 ft scans do not cover all the ground under the aircraft because of the limited maximum scan rate and the minimum airspeed of the aircraft. The best scan overlap (approximately 50%) occurs at a flight altitude of 2000 ft above terrain and at a ground speed of 120 knots. The fixed scan rate produces increasing scan overlap at higher altitudes.

The nominal unobscured FOV of the scanners is 80° across the flight line and continuous in the flight direction. However, when the thermal reference plates are used with scanner 1, the unobscured external FOV is reduced to 37°. The lamp reference sources for scanner 2 are registered during the period of internal scan so that the external FOV for this scanner is unaffected by the calibration sources. The synchronization signal is stabilized about the roll axis to reduce significant pattern distortion in the imagery representing scanned terrain. No corrections are made for aircraft pitch and yaw during the scan.

The system will register quantitatively in nineteen bands on magnetic tape the spectral signature of targets as small as several resolution elements (approximately 10-ft diameter at 1000-ft altitude). The quantitative measure of the signal level (radiance) in each band is established by interpolation between two known radiation inputs at the scanner aperture. The radiation inputs are common to data channels within a scanner and can be compared between scanners.



(a) External View

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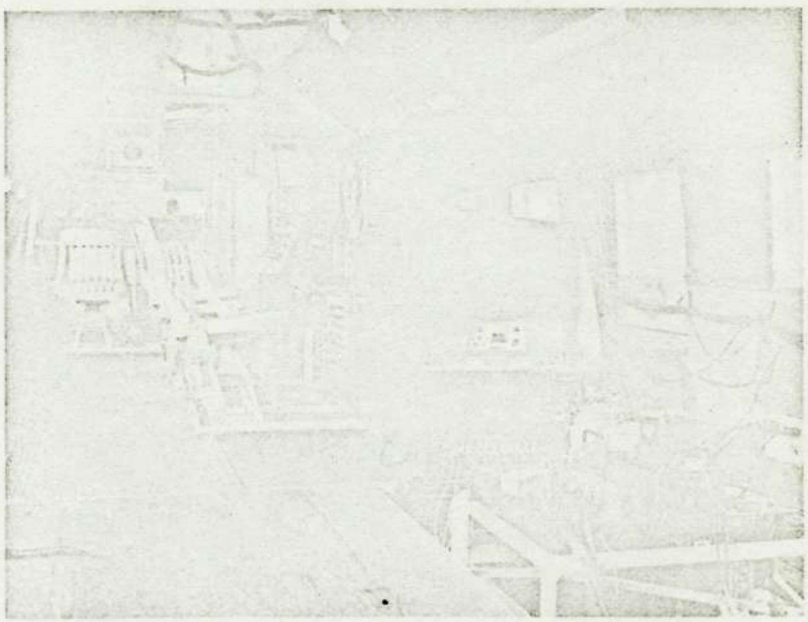
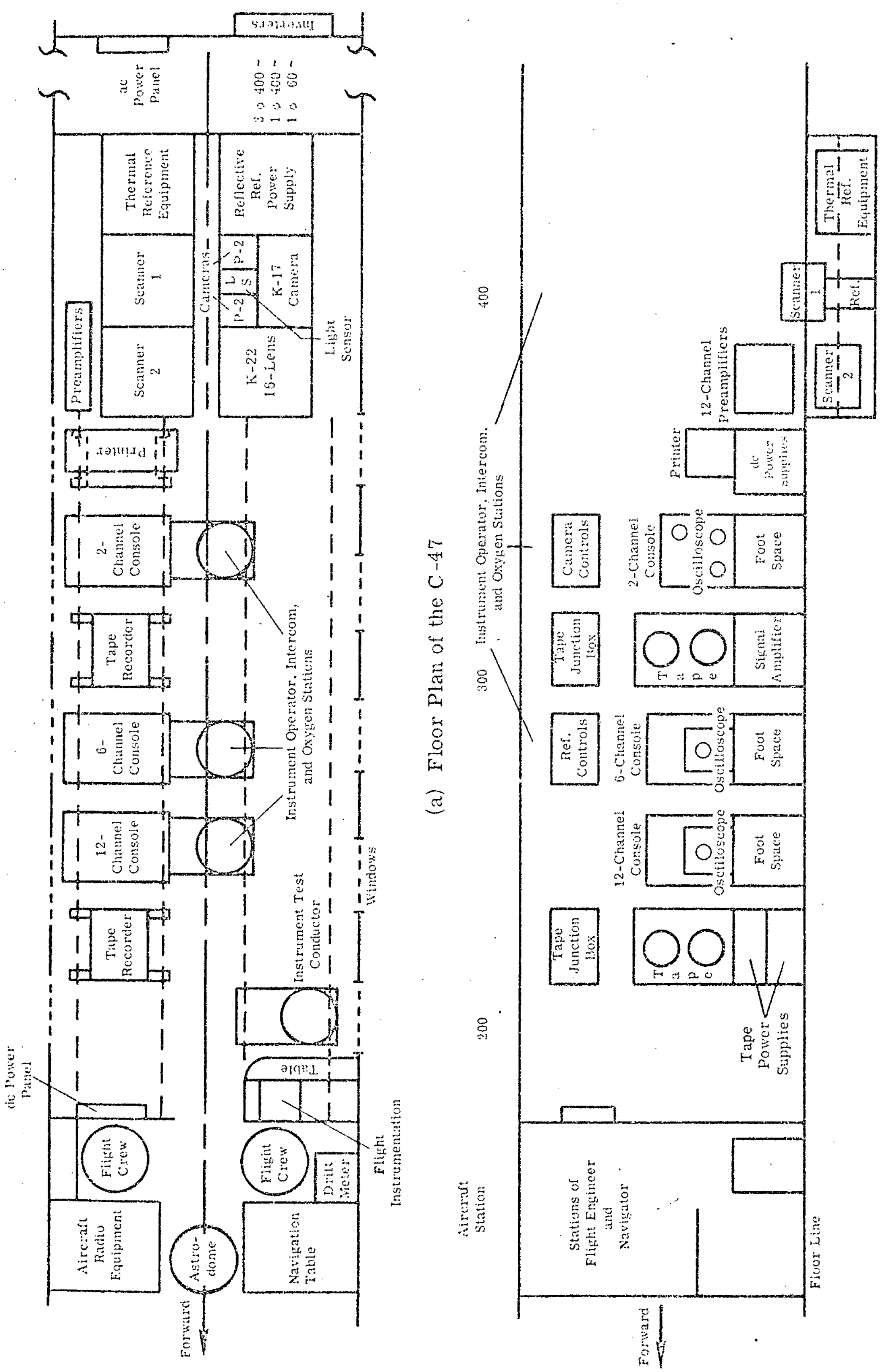


(b) Internal View

FIGURE 3. C-47 AIRCRAFT INSTRUMENTED AND OPERATED AT WILLOW RUN LABORATORIES



(a) Floor Plan of the C-47

(b) Starboard Side of the Interior

FIGURE 4. LAYOUT OF THE INSTRUMENTATION IN THE C-47 AIRCRAFT

3.2. DATA REPRODUCTION AND DATA HANDLING

Although some data reproduction can be done with the airborne equipment in the field to obtain preliminary results, the majority of the reproduction is accomplished at WRL. The scanner imagery is reproduced in two basic forms for distribution to data users: analog magnetic tapes and film strips.

The original analog tapes are duplicated when the original tape is played back on one tape machine and the electrical signal is transferred to a second tape machine. The electronics of both machines were modified by Willow Run to transfer the electrical signal between tapes with minimum signal degradation. The scanner signals are FM recorded to preserve low-frequency information and must be demodulated for restoration to the original form. The tape duplications are made without going through the demodulation and remodulation of the signal. All tape duplications are made from the original analog tape which is retained on file.

The scanner imagery is reproduced on 70-mm film strips in the data-playback facility. This facility contains 1-in. and 1/2-in. tape machines, signal-handling equipment, operator displays and controls, and a cathode-ray tube (CRT)/film printer. The signal-handling equipment provides special video bandwidth filtering, amplification, gating, clamping, sampling, and holding circuitry to allow maximum retention of information and reformatting of the data on film. In reformatting (see Fig. 5), the calibration reference sources are sampled, stored, and mixed with the gated video at the appropriate time so that maximum use is made of the 70-mm film area. This radiation reference information is printed beside the scene imagery in a continuous film strip. Periodically (usually between runs), the scene imagery is interrupted by the insertion of a 16-step, equal-voltage-increment grey scale across the film width. Thus, the film retains a quantitative correlation between film tone and signal voltage, regardless of the processing variables. The film drive for the CRT/printer was adapted from a magnetic tape-machine belt drive to provide smooth and accurate film motion for printing the line scan imagery. The printer camera originally contained a gear drive which did not operate smoothly. A unique feature of the facility is a flying-spot-scanner labeling device which introduces identifying nomenclature onto the beginning of each film strip.

All reproduced data are reviewed and distributed by the same personnel who collected the data. Thus, equipment performance degradations or malfunctions are noted promptly and are corrected immediately after their discovery.

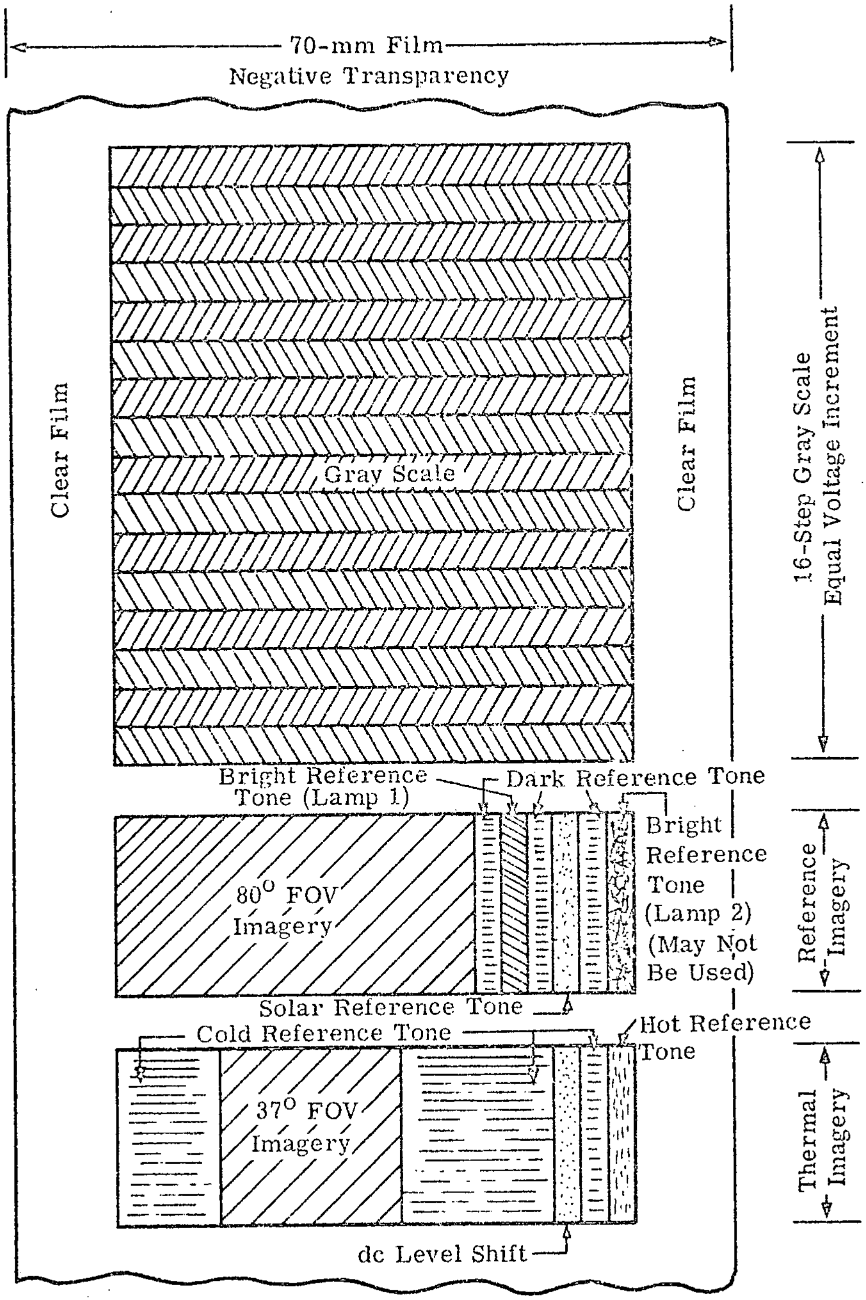


FIGURE 5. ILLUSTRATION OF SCANNER IMAGERY REPRODUCTION ON FILM

4 RECOMMENDATIONS

We have completed two-and-one-half years of multispectral data-collection operations for NASA/MSC and over five years total with this particular equipment. Our experience has led to several recommendations to improve multispectral data-collection functions. The major deficiency in the current system, i.e., the lack of common registration in the multispectral imagery, has been corrected. Multispectral data could be machine processed from only one detector assembly at a time. The new Michigan scanner, which will be operational beginning in FY 1972, will provide common line-of-sight registration to three detector assemblies. Other areas of improvement which should be considered for the future are noted as follows:

(1) Resources should be made available for continued improvement of equipment performance through refinements in radiation reference sources and new detector developments.

(2) Supporting equipment should be added to the airborne system to provide accurate aircraft position and attitude information so that accurate multispectral area maps can be produced.

(3) The data-reproduction equipment should be modified so that it can use the aircraft position and attitude information to provide accurately scaled multispectral maps.

(4) Provisions should be made in the data-collection system for efficient and accurate retrieval of recorded data.

(5) The feasibility of active, scanning systems which use laser sources should be investigated for earth-resources applications.

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Appendix I
SCANNER DATA-COLLECTION FLIGHTS IN 1968*

NASA Mission No.	Date	Time	Area	Ultraviolet (0.3-0.4 μm)	Visible (0.4-0.7 μm)	Near Infrared (0.7-3.0 μm)	Middle Infrared (3.0-6.0 μm)	Far Infrared (8.0-14.0 μm)
	**5/22/68	1000	Local Agriculture		8	5	1	1
	**5/31/68	0730	Jamestown, North Dakota		8	5	1	1
	**5/29/68	0830	Black Hills, South Dakota		8	5	1	1
	**5/29/68	1130	Black Hills, South Dakota		8	5	1	1
	**5/29/68	1400	Black Hills, South Dakota		8	5	1	1
	**5/30/68	0730	Black Hills, South Dakota		8	5	1	1
	**7/25/68	0900	Local Agriculture		8	5	1	1
	**7/30/68	0900	Lafayette, Indiana		8	5	1	1
	**8/22/68	1000	Local Agriculture		8	5	1	1
	9/9/68	1330	Local Test		8	5	1	1
	**9/17/68	0800	Ft. Collins, Colorado		8	5	1	1
	**9/20/68	0900	Sacramento, California		8	5	1	1
	**9/23/68	0900	Mono Lake, California		8	4	2	2
1M	9/26/68	0900	Lafayette, Indiana		8	5	1	1
	**9/26/68	1400	Lake Michigan		8	5	1	1
2M	10/15/68	1000	Knoxville, Tennessee		8	5	1	1
	**10/21/68	1030	Local Forestry		8	5	1	1

*Number in column indicates scanner data channels in that spectral region.
**Data-collection flights for sponsors other than NASA.

Appendix II
SCANNER DATA-COLLECTION FLIGHTS IN 1969*

NASA Mission No.	Date	Time	Area	Ultraviolet (0.3-0.4 μm)	Visible (0.4-0.7 μm)	Near Infrared (0.7-3.0 μm)	Middle Infrared (3.0-6.0 μm)	Far Infrared (8.0-14.0 μm)
	2/26/69	1100	Local Test		8	5	1	1
	**3/6/69	1500	Santa Barbara, California		8	5	1	1
	**3/7/69	0615	Santa Barbara, California	1	9	4	1	1
	**3/7/69	1130	Santa Barbara, California		9	4	1	2
3M	3/8/69	1100	San Diego, California		8	5	1	1
3M	3/12/69	0900	San Diego, California		8	5	1	1
	5/12/69	0945	Local Test		8	5	1	1
4M	5/13/69	0800	Lafayette, Indiana		8	5	1	1
	**5/15/69	1200	Harrisburg, Pennsylvania		9	4	1	1
	**5/15/69	2100	Harrisburg, Pennsylvania			1	2	2
4M	5/26/69	1100	Lafayette, Indiana		8	5	1	1
4M	5/27/69	1100	Lafayette, Indiana		8	5	1	1
	**5/27/69	1330	Lake Michigan		10	5	1	1
	**6/9/69	1115	Eglin Test Site, Florida		8	4	2	2
	**6/10/69	1115	Eglin Test Site, Florida		8	4	2	2
	**6/10/69	2245	Eglin Test Site, Florida			2	2	2
	**6/11/69	0315	Eglin Test Site, Florida			2	2	2
	**6/12/69	2245	Eglin Test Site, Florida			2	2	2
	**6/13/69	1115	Eglin Test Site, Florida		8	4	2	2
	**6/13/69	1615	Eglin Test Site, Florida		8	4	2	2
	**6/14/69	0315	Eglin Test Site, Florida			2	2	2
5M	6/25/69	1100	Lafayette, Indiana		8	5	1	1
5M	6/25/69	1700	Lafayette, Indiana		8	5	1	1
5M	6/26/69	1030	Lafayette, Indiana		8	5	1	1
6M	7/3/69	1400	Oregon Coast, Oregon		7	1	1	2
6M	7/5/69	0900	Oregon Coast, Oregon		7	1	1	2
6M	7/5/69	1430	Oregon Coast, Oregon		7	1	1	2
6M	7/6/69	1130	Oregon Coast, Oregon		7	1	1	2
6M	7/8/69	1130	Oregon Coast, Oregon		7	1	1	2
6M	7/12/69	0900	Oregon Coast, Oregon		7	1	1	2
6M	7/12/69	1500	Oregon Coast, Oregon		7	1	1	2
6M	7/13/69	0900	Oregon Coast, Oregon		7	1	1	2
6M	7/13/69	1400	Oregon Coast, Oregon		7	1	1	2
6M	7/14/69	0800	Wind River, Washington		8	5	1	1
6M	7/14/69	1330	Wind River, Washington		8	5	1	1
6M	7/15/69	0630	Wind River, Washington		8	5	1	1
6M	7/15/69	1030	Wind River, Washington		8	5	1	1
6M	7/16/69	1000	Bucks Lake, California		8	5	1	1
6M	7/21/69	1030	Black Hills, South Dakota		8	5	1	1
6M	7/21/69	1430	Black Hills, South Dakota		8	5	1	1
6M	7/22/69	0830	Black Hills, South Dakota		8	5	1	1
6M	7/22/69	1230	Black Hills, South Dakota		8	5	1	1
6M	7/23/69	0245	Missouri River, Missouri				1	2
7M	8/4/69	0930	Ann Arbor, Michigan		8	5	1	1
7M	8/5/69	0700	Lafayette, Indiana		8	5	1	1

7M	8/5/69	1030	Lafayette, Indiana		8	5	1	1
7M	8/6/69	1030	Lafayette, Indiana		8	5	1	1
	**8/11/69	0930	Lake Michigan, Michigan	1	7	2	1	1
7M	8/11/69	0930	Lake Michigan, Michigan	1	7	2	1	1
7M	8/13/69	0900	Ann Arbor, Michigan		8	5	1	1
	**8/13/69	0900	Detroit River		8	5	1	1
7M	8/13/69	2100	Ann Arbor, Michigan				2	1
	**8/13/69	2100	Detroit River				2	1
8M	9/3/69	0715	Washtenaw County, Michigan		8	5	1	1
8M	9/3/69	1100	Washtenaw County, Michigan		8	5	1	1
8M	9/14/69	0900	Oregon Coast, Oregon	1	7	1	1	1
8M	9/15/69	1045	Oregon Coast, Oregon	1	8	1	1	1
8M	9/15/69	1500	Oregon Coast, Oregon	1	8	1	1	1
8M	9/21/69	1000	Oregon Coast, Oregon	1	8	1	1	1
8M	9/23/69	0900	Oregon Coast, Oregon	1	8	1	1	1
8M	9/23/69	1330	Oregon Coast, Oregon	1	8	1	1	1
8M	9/24/69	1300	Oregon Coast, Oregon	1	8	1	1	1
8M	9/25/69	1000	Moses Lake, Washington		8	5	1	1
8M	9/26/69	0730	Wind River, Washington		8	5	1	1
8M	9/26/69	1030	Wind River, Washington		8	5	1	1
	**10/22/69	0930	Moses Lake, Washington		8	5	1	1
	**10/22/69	1430	Moses Lake, Washington		8	5	1	1
	**10/22/69	1900	Moses Lake, Washington			3	1	1
	**10/23/69	0530	Moses Lake, Washington			3	1	1
8M	10/24/69	1200	Bucks Lake, California		8	5	1	1
	**10/25/69	1330	L. A. Forestry, California		8	5	1	1
	**10/27/69	0800	L. A. Forestry, California		8	5	1	1
	**10/27/69	1030	L. A. Forestry, California		8	5	1	1
9M	11/5/69	1300	Lafayette, Indiana		8	5	1	1
9M	11/6/69	0830	Lafayette, Indiana		8	5	1	1
9M	11/6/69	1100	Lafayette, Indiana		8	5	1	1
	**11/20/69	1000	Detroit River, Michigan		10	5		1
8M	11/26/69	1000	Ann Arbor, Michigan		8	5	1	1
	**11/26/69	1000	Detroit River, Michigan		8	5	1	1
10M	12/17/69	1200	Lafayette, Indiana		8	5	1	1

*Number in column indicates scanner data channels in that spectral region.

**Data-collection flights for sponsors other than NASA.

Appendix III
SCANNER DATA-COLLECTION FLIGHTS IN 1970

NASA Mission No.	Date	Time	Area	Flight (miles)	Ultraviolet (0.3-0.4 μm)	Visible (0.4-0.7 μm)	Near Infrared (0.7-3.0 μm)	Middle Infrared (3.0-6.0 μm)	Far Infrared (8.0-14.0 μm)
	3/5/70	1100	Local Test	52	0	11	3	1	1
11M	3/10/70	0830	Biscayne Bay, Florida	132	1	12	0	1	1
11M	3/11/70	0830	Florida Keys, Florida	52	1	12	3	0	1
	**3/26/70	2300	Kansas City, Kansas	50	0	0	0	1	3
	**4/4/70	1400	Kansas City, Kansas	48	0	12	3	1	1
	**4/7/70	2330	Staunton, Virginia	24	0	0	0	1	3
	**4/8/70	1000	Staunton, Virginia	24	0	12	3	0	1
12M	5/6/70	0900	Lafayette, Indiana	124	0	12	3	1	1
12M	5/7/70	1300	Lafayette, Indiana	155	0	12	3	1	1
	**5/7/70	1400	Lake Michigan, Michigan	39	0	10	0	1	3
14M	5/21/70	1530	North Dakota	40	0	12	3	0	1
14M	5/22/70	0900	North Dakota	152	1	12	3	0	1
14M	5/23/70	0030	North Dakota	48	0	0	0	1	3
14M	5/23/70	0930	Minnesota	43	0	12	3	0	1
	6/5/70	1430	Local Test	10	0	0	3	0	2
15M	6/8/70	0900	Ann Arbor, Michigan	38	1	12	3	0	1
	6/9/70	1430	Local Test	10	0	0	3	0	2
15M	6/20/70	0730	Washtenaw County, Michigan	55	1	12	3	0	1
15M	6/20/70	1030	Washtenaw County, Michigan	25	1	12	3	0	1
16M	6/23/70	1330	Mill Creek Test Flight	26	1	12	0	0	2
16M	6/24/70	1200	Mill Creek, Oklahoma	78	1	12	0	0	2
16M	6/24/70	1500	Mill Creek, Oklahoma	78	1	12	0	0	2
16M	6/25/70	0500	Mill Creek, Oklahoma	56	0	0	0	1	3
16M	6/25/70	0900	Mill Creek, Oklahoma	78	1	12	0	0	3
16M	6/26/70	0500	Mill Creek, Oklahoma	56	0	0	0	1	3
16M	6/26/70	0900	Mill Creek, Oklahoma	78	1	12	0	1	2
17M	6/30/70	0930	Lafayette, Indiana	107	0	12	3	1	1
17M	7/1/70	0500	Lafayette, Indiana	24	0	0	0	1	3
17M	7/1/70	0930	Lafayette, Indiana	137	0	12	3	1	1
18M	7/6/70	1400	Ann Arbor, Michigan	44	0	12	3	1	1
18M	7/7/70	0900	Ann Arbor, Michigan	33	0	12	3	1	1
	**7/13/70	1300	Dundee, Michigan	27	0	12	0	2	1
	**7/16/70	1200	Pellston, Michigan	21	1	12	3	0	1
	**7/17/70	0400	Pellston, Michigan	15	0	12	0	1	2
	**7/17/70	0900	Traverse Bay, Michigan	160	1	12	0	0	2
	**7/21/70	1530	Dundee, Michigan	10	0	12	0	2	1
	**7/22/70	0700	Dundee, Michigan	10	0	12	0	2	1
19M	7/28/70	0700	Manitou, Colorado	18	0	12	3	1	1
19M	7/28/70	1100	Manitou, Colorado	18	0	12	3	1	1
19M	7/28/70	1500	Manitou, Colorado	18	0	12	3	1	1
19M	7/31/70	0930	North Dakota	64	0	12	3	1	1
19M	7/31/70	2330	North Dakota	48	0	0	0	0	3
20M	8/5/70	1000	Ann Arbor, Michigan	43	0	12	3	1	1
20M	8/6/70	0130	Ann Arbor, Michigan	19	0	0	0	1	3
20M	8/11/70	1330	Lafayette, Indiana	103	0	12	3	1	1
20M	8/13/70	1430	Lafayette, Indiana	130	0	12	3	1	1

20M	8/21/70	0730	Washtenaw County, Michigan	55	1	12	3	0	1
20M	8/21/70	1030	Washtenaw County, Michigan	23	1	12	3	0	1
21M	8/27/70	1000	Cathcart Mt., Maine	10	0	12	3	0	3
21M	8/27/70	2000	Cathcart Mt., Maine	12	0	0	0	1	3
22M	9/18/70	0830	Alafia/Peace, Florida	99	1	12	3	0	1
22M	9/19/70	0800	Alafia/Peace, Florida	70	1	12	3	0	1
22M	9/20/70	0330	Alafia/Peace, Florida	93	0	0	0	0	4
22M	9/21/70	0430	Alafia/Peace, Florida	61	0	0	0	0	4
24M	9/29/70	0600	Ann Arbor, Michigan	23	0	12	3	0	3
24M	10/1/70	1000	Ann Arbor, Michigan	48	0	12	3	0	3
26M	10/16/70	0001	Ann Arbor, Michigan	9	0	0	0	0	4
26M	10/16/70	0300	Ann Arbor, Michigan	14	0	0	0	0	4
26M	10/16/70	0600	Ann Arbor, Michigan	9	0	0	0	0	4
26M	10/16/70	0900	Ann Arbor, Michigan	26	0	12	3	0	3
28M	8/24/70	1100	Grain Belt, Indiana	62	0	12	3	1	1
28M	8/24/70	1630	Grain Belt, Indiana	62	0	12	3	1	1
28M	9/5/70	0900	Grain Belt, Indiana	134	0	12	3	1	1
28M	9/5/70	1400	Grain Belt, Indiana	62	0	12	3	1	1
28M	9/11/70	0900	Grain Belt, Indiana	62	0	12	3	1	1
28M	9/11/70	1300	Grain Belt, Indiana	62	0	12	3	1	1
	**9/9/70	0900	Power Plants, Michigan	17	0	12	0	0	4
	**10/28/70	1200	Oxnard, California	18	1	12	3	0	1
	**10/28/70	1600	Oxnard, California	18	1	12	0	1	1
29M	11/4/70	1400	Chesapeake Bay, Maryland	6	1	12	3	0	1
29M	11/5/70	1330	Chesapeake Bay, Maryland	38	1	12	2	0	1
29M	11/6/70	0830	Chesapeake Bay, Maryland	115	1	12	2	0	1
31M	10/29/70	0800	Pisgah Crater, California	26	1	12	0	0	3
31M	10/30/70	0730	Pisgah Crater, California	34	1	12	0	0	3
	**12/14/70	2200	Staunton, Virginia	24	0	0	0	1	3
	**12/15/70	1000	Staunton, Virginia	36	0	12	3	0	1

*Number in column indicates scanner data channels in that spectral region.

**Data-collection flights for sponsors other than NASA.

Appendix IV
SCANNER DATA-COLLECTION FLIGHTS DURING JANUARY THROUGH JUNE 1971

NASA Mission No.	Date	Time	Area	Flight (miles)	Ultraviolet (0.3-0.4 μm)	Visible (0.4-0.7 μm)	Near Infrared (0.7-3.0 μm)	Middle Infrared (3.0-6.0 μm)	Far Infrared (8.0-14.0 μm)
32M	2/27/71	1300	Weslaco, Texas	49	0	12	3	0	2
32M	3/3/71	0550	Weslaco, Texas	43	0	0	0	1	2
32M	3/4/71	0550	Weslaco, Texas	43	0	0	0	1	2
34M	3/11/71	0900	Tenn. Valley, Tennessee	90	0	12	3	1	1
35M	3/4/71	1100	Port Lavaca Bay, Texas	28	1	12	0	0	3
35M	3/8/71	0800	Houston, Texas	43	1	12	0	0	1
35M	3/8/71	1200	Houston, Texas	43	1	12	0	0	1
35M	3/8/71	1600	Houston, Texas	33	1	2	0	0	1
35M	3/8/71	2000	Houston, Texas	32	0	0	0	0	3
35M	3/9/71	0000	Houston, Texas	32	0	0	0	0	3
35M	3/9/71	0400	Houston, Texas	32	0	0	0	0	3
	4/21/71	1400	Local Test	10	1	12	0	0	2
	**4/22/71	0800	Lake Michigan, Michigan	72	1	12	0	0	2
	**4/22/71	1430	Lake Michigan, Michigan	38	1	12	0	0	2
	**4/22/71	1830	Lake Michigan, Michigan	33	1	12	0	0	2
	**4/23/71	0900	Lake Michigan, Michigan	75	1	12	0	0	2
	**4/23/71	1330	Lake Michigan, Michigan	33	1	12	0	0	2
	**4/23/71	1700	Lake Michigan, Michigan	41	1	12	0	0	2
	**4/30/71	0800	Lake Michigan, Michigan	59	1	12	0	0	2
	**4/30/71	1330	Lake Michigan, Michigan	19	1	12	0	0	2
	**5/5/71	0900	Sumpter Township, Mich.	57	1	12	3	0	1
	**5/7/71	0900	Lake Michigan, Michigan	80	1	12	0	0	2
	**5/10/71	0900	Lake Ontario, New York	34	1	11	0	0	2
	**5/10/71	1330	Lake Ontario, New York	130	1	11	0	0	2
	**5/11/71	0400	Lake Ontario, New York	48	0	0	0	0	2
	**5/11/71	1200	Lake Ontario, New York	168	0	12	3	0	2
38M	5/17/71	1130	Corn Blight, Indiana	57	0	12	3	1	1
38M	5/17/71	1300	Corn Blight, Indiana	52	0	12	3	1	1
38M	5/21/71	1000	Corn Blight, Indiana	40	0	12	3	1	1
38M	5/21/71	1130	Corn Blight, Indiana	51	0	12	3	1	1
38M	5/22/71	1000	Corn Blight, Indiana	46	0	12	3	1	1
38M	5/22/71	1130	Corn Blight, Indiana	61	0	12	3	1	1
	**5/22/71	1500	MSU Ag. Farm, Michigan	16	0	12	3	1	1
	**5/28/71	0900	Lake Michigan, Michigan	80	1	12	0	0	2
	**5/28/71	1600	Lake Michigan, Michigan	73	1	12	0	0	2

*Number in column indicates scanner data channels in that spectral region.

**Data-collection flights for sponsors other than NASA.

Appendix V
TENTATIVE FLIGHT SCHEDULE FOR FISCAL YEAR 1972

Date	Mission	Operations Base	Aircraft	Data (miles)
6/28-7/2	40M, Corn Blight	Lafayette, Indiana	C-47	300
7/5-9	40M, Corn Blight	Lafayette, Indiana	C-47	
7/12-16	41M, Corn Blight	Lafayette, Indiana	C-47	300
7/19-23	41M, Corn Blight	Lafayette, Indiana	C-47	
7/26-30	42M, Corn Blight	Lafayette, Indiana	C-47	300
8/2-6	42M, Corn Blight	Lafayette, Indiana	C-47	
8/2-6	Ingham County (prime)	Lansing, Michigan	C-47	240
8/9-13	43M, Corn Blight	Lafayette, Indiana	C-47	300
8/16-20	43M, Corn Blight	Lafayette, Indiana	C-47	
8/16-20	Ingham County (enroute)	Lansing, Michigan	C-47	24
8/23-27	44M, Corn Blight	Lafayette, Indiana	C-47	300
8/30-9/3	44M, Corn Blight	Lafayette, Indiana	C-47	
9/6-10	45M, Corn Blight	Lafayette, Indiana	C-47	300
9/13-17	45M, Corn Blight	Lafayette, Indiana	C-47	
*9/13-17	Genesee County	Flint, Michigan	C-47	200
9/20-24	46M, Corn Blight	Lafayette, Indiana	C-47	300
9/20-24	Ingham County (enroute)	Lansing, Michigan	C-47	24
*9/27-10/1	Eglin	Eglin AFB, Florida	C-47	100
10/4-8	46M, Corn Blight	Lafayette, Indiana	C-47	
10/11-15				
10/18-22				
10/25-29	Ann Arbor/Lake Michigan	WRL, Michigan	C-46	40/90
11/1-5	Atlanta	Atlanta, Georgia	C-46	100
11/8-12	HATS	Houston, Texas	C-46	150
12/6-10				
12/13-17				
12/20-24				
12/27-31				
1/3-7				
1/10-14				
1/17-21				
1/24-28				
1/31-2/4				
2/7-11				
2/14-18				
2/21-25				
2/28-3/3				
3/6-10				
3/13-17				
3/20-24				
3/27-31				
4/3-7				
4/10-14				
4/17-21				
4/24-28	Test Flight	WRL, Michigan	C-47	
5/1-5	54M, Ann Arbor	WRL, Michigan	C-47	60
5/8-12	55M, Baltimore	Baltimore, Maryland	C-47	140
5/15-19	Woodworth (255)	Jamestown, North Dakota	C-47	306
5/22-26	Black Hills (226)	Rapid City, South Dakota	C-47	40
5/29-6/2	57M, Ann Arbor	WRL, Michigan	C-47	60
*6/5-9	Lake Ontario	Niagara, New York	C-47	500
6/12-16	Oakland Co. (086)	WRL, Michigan	C-47	75
6/19-23	Eaton Co. (136, 321)	Local	C-47	120
6/26-30	Atlanta (226)	Macon, Georgia	C-47	80

*Data-collection flights for sponsors other than NASA.

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